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FINAL REPORT
LABORATORY DEVELOPMENT OF
COMPUTER GENERATED IMAGE DISPLAYS
FOR EVALUATION IN
TERRAIN FLIGHT TRAINING

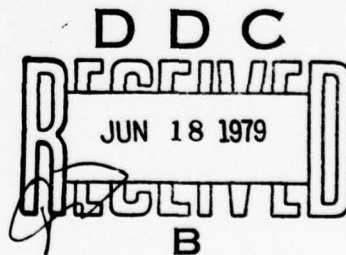CONTRACT DAHC 19-77-C-0006

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

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GROUND SYSTEMS DEPARTMENT
SPACE DIVISION
GENERAL ELECTRIC COMPANY
DAYTONA BEACH, FLORIDA

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This report describes the formulation of a digital data base and the equipment utilized to display computer generated images of the resultant terrain scenes. Real time and nonreal time equipment is described. Necessary input data for formulation of digital data bases is delineated. Resulting scene data is to be utilized as stimulus material for evaluation of CGI systems to determine their effectiveness as a medium for training navigators and pilots.

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FOREWORD

The Army Research Institute Field Unit at Fort Rucker, Alabama supports the Army's Training Development and Material Development Agencies through its in-house research and development efforts, augmented by contracts with organizations selected as having unique capabilities and facilities in a specific area. This report documents work conducted by the General Electric Company, Space Division, under Contract DAHC19-77-C-0006, to provide stimulus materials for the evaluation of day-night Computer Image Generation systems.

The entire program of aviation training research and development is responsive to the requirements of RDT&E Project 2Q763743A772, Aircrew Performance Enhancement in the Tactical Environment.

JOSEPH ZEIDNER
Technical Director

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INTRODUCTION

This report describes the purpose, techniques and results of the work performed on contract DAHC 19-77-C-0006 sponsored by the U.S. Army Research Institute for the Behavioral and Social Sciences and performed by the General Electric Company, Space Division, Daytona Beach, Florida. The ARI Contracting Officier's Technical Representative was Dr. James A. Bynum of the ARI Field Unit, Ft. Rucker, Alabama.

The purpose of this contract was to provide stimulus material to ARI to allow evaluation of day-night Computer Image Generator (CIG) systems for the training of navigators and pilots of helicopters in Nap of the Earth (NOE) flight operations.

Two techniques were planned to generate the necessary computer generated visual scene data. First was the production of three motion picture film strips for each of three tracks over a special visual data base using a real time laboratory CIG system. The second was the production of forty-eight still photographs of three different levels of scene detail made on the nonreal time CIG system.

DESCRIPTION OF EQUIPMENT USED

REAL TIME CIG SYSTEM

The real time CIG system used was a development system located in the engineering laboratory of General Electric's Daytona Beach facility. The specifications for this system are given in Table 1 and a simple block diagram is shown in Figure 1.

A real time CIG system operates by utilizing a three dimensional description, in digital form, of the geographical area in which it is desired to operate. This mathematical description is a simplified representation of the real world. The general purpose computer accepts real time flight control signals or may follow a preprogrammed path. It furnishes information describing the pilot's aircraft location altitude, attitude, and the desired field of view to the image generator which then searches the stored mathematical description and processes the data necessary to generate the desired scene. The resulting video signals are displayed on virtual image CRT devices beginning at the third TV frame (a frame = 1/30 second) after the input frame during which the position information was received.

The generated scenes were visible on a special design TV monitor which operates at 763 TV lines per frame, a nonstandard rate and not compatible with available TV video recording devices, all of which are designed for 525 TV lines per frame. Therefore, to record the visual scenes, a color TV camera was used as a scan converter and the results recorded on a high quality TV video tape recorder. This video tape was specially processed to obtain a 16mm film.

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Table 1. Characteristics Laboratory Real Time Laboratory System

|	
Gaming Area	340 x 340 NM
Lighting Conditions of scene	Variable - Day/Night
Potentially visible edges	2,048
Potentially visible faces	512
Potentially visible point features	2,048 (Variable size)
Potentially visible models (2D and 3D)	256
Priority list size	256
Moving models	8
Levels of Detail	8
Automatic overload correction	Yes
Edge Crossings per system raster line	340
Edge Crossings per channel raster line	256
Point Features per system raster line	340
Point Features per channel raster line	256
Video Raster lines per frame	763
Number of display channels	2 (Expandable to 3 or more)
Display type	Virtual Image CRT
Display resolution, arc min H&V	2.7
Display brightness, footlamberts	6
Display Field of View (each)	$30^{o}V$ by $40^{o}H$
Color Displays	Yes
Color hues possible	256^{3}
Face color hues available at one time	64
Light color hues available at one time	16
Light characteristics available	64
Curved Surface shading	No
Sun shading	No
Face color blending	Yes
Fog, Aerial perspective, clouds, horizon	Yes
Edge smoothing, horizontal and vertical	Yes
General purpose computer	PDP 11/55
GP Computer peripherals	
Card Reader	Yes
Line Printer	Yes
Magnetic Tape	Yes
Disks	Yes
CRT Terminal	Yes
Number of cabinets, image generator	8
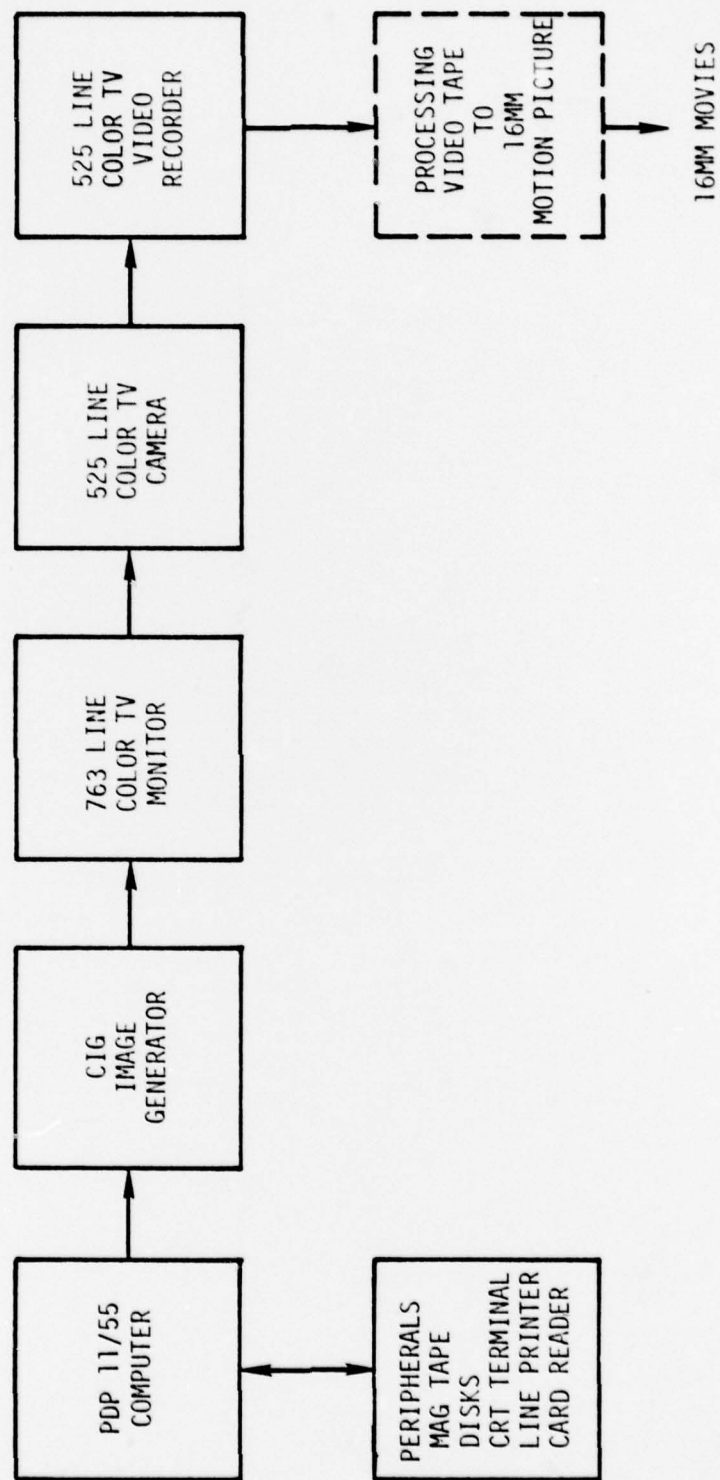
Figure 1. Real Time Image Generator

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NONREAL TIME CIG SYSTEM

In the nonreal time CIG system, all of the scene processing from a visual data base takes place in a general purpose computer. The generation of a complex scene takes many hours using the PDP 11/35 and minutes in the VAX 11/780 compared to the 1/30 of a second obtained using a real time system.

The arrangement of the nonreal time CIG system is given in Figure 2. The basic system consists of the PDP 11/35 computer and its peripherals. The generated scene can be displayed on three devices. The first is a high resolution storage tube whose generated scene can be recorded by a Polaroid camera. This is commonly referred to as the Dicomed, in reference to its manufacturer. This equipment was used for some steps. The second and third devices both receive data via an intermediate digital memory. The second device is a video frame recorder which can then transfer its information to a video tape recorder. This device was not used, because until very recently, it was extremely unreliable. The third device is a standard TV color monitor whose input is derived each frame time from the digital memory, called a refresh memory in this case. The output of this monitor was photographed to get the desired still photographs.

Recently the VAX 11/780 has become available and has been used to shorten the computation time, storing its output on a magnetic tape.

VISUAL DATA BASE

As part of the present training program for NOE navigation, the U.S. Army utilizes a Map Interpretation and Terrain Analysis Course. A part of the area of Route R-27 was selected for formulation of the digital data base for scene generation. This course was located near Petrey, Alabama, and was centered near Longitude 86° 11' W and Latitude 31° 47'30" N. The area selected is shown in Figure 3.

In order to best follow the modeling rules and to stay within the system capabilities, the visual data base areas were divided into eight sectors. These sectors and the coordinate system used are shown in Figure 4. This same area and sectors were used for the real time and nonreal time scenes.

In the case of the static scenes, five aiming point or target areas were specified with each aiming point viewed from three viewpoint locations. A sixth aiming point was viewed from only one viewpoint. For each viewpoint nonreal time separate scenes were generated containing 2000, 4000, or 8000 edges. The location of the aiming points and viewpoints is given in Table 2 and is shown in Figure 5.

The visual data base for the real time system was prepared following the standard rules and constraints for that system. This system had been designed with the concept of utilizing flat faces lying in the ground or Z=0 plane, with these faces used to simulate roads, fields, rivers, lakes, etc. Very few three dimensional objects were to be used. This concept was acceptable for the planned uses of the system.
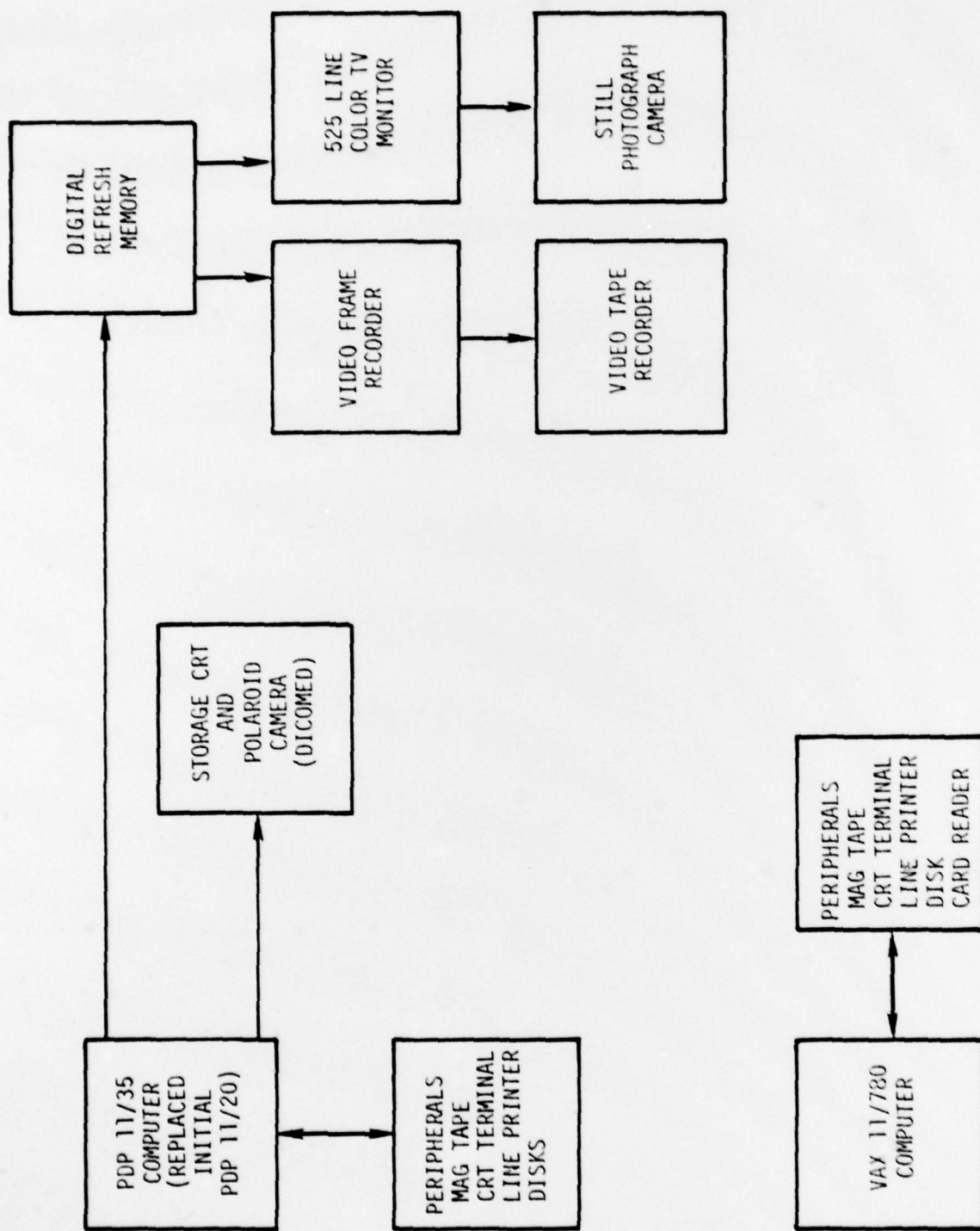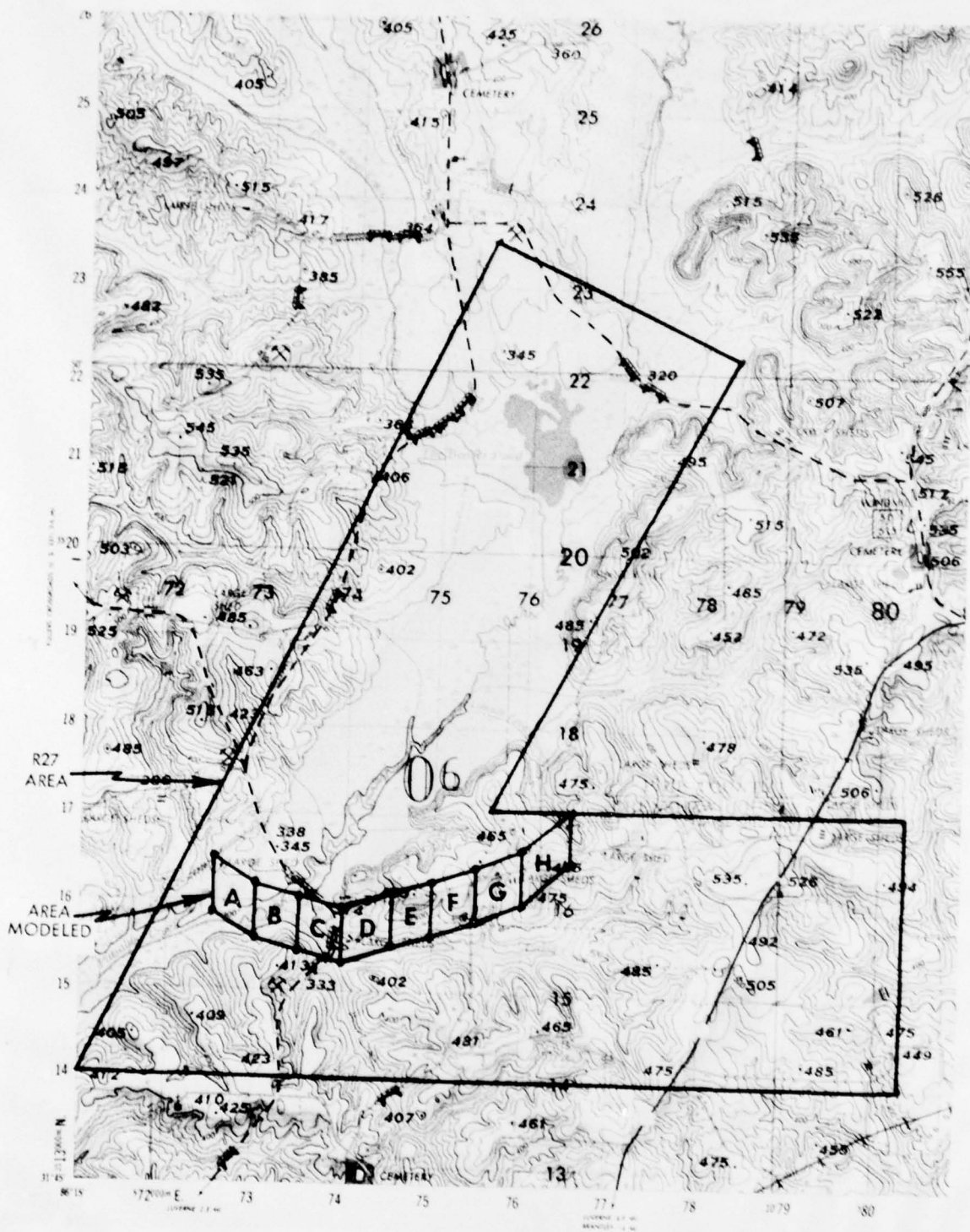
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Figure 2. Nonreal Time CIG System
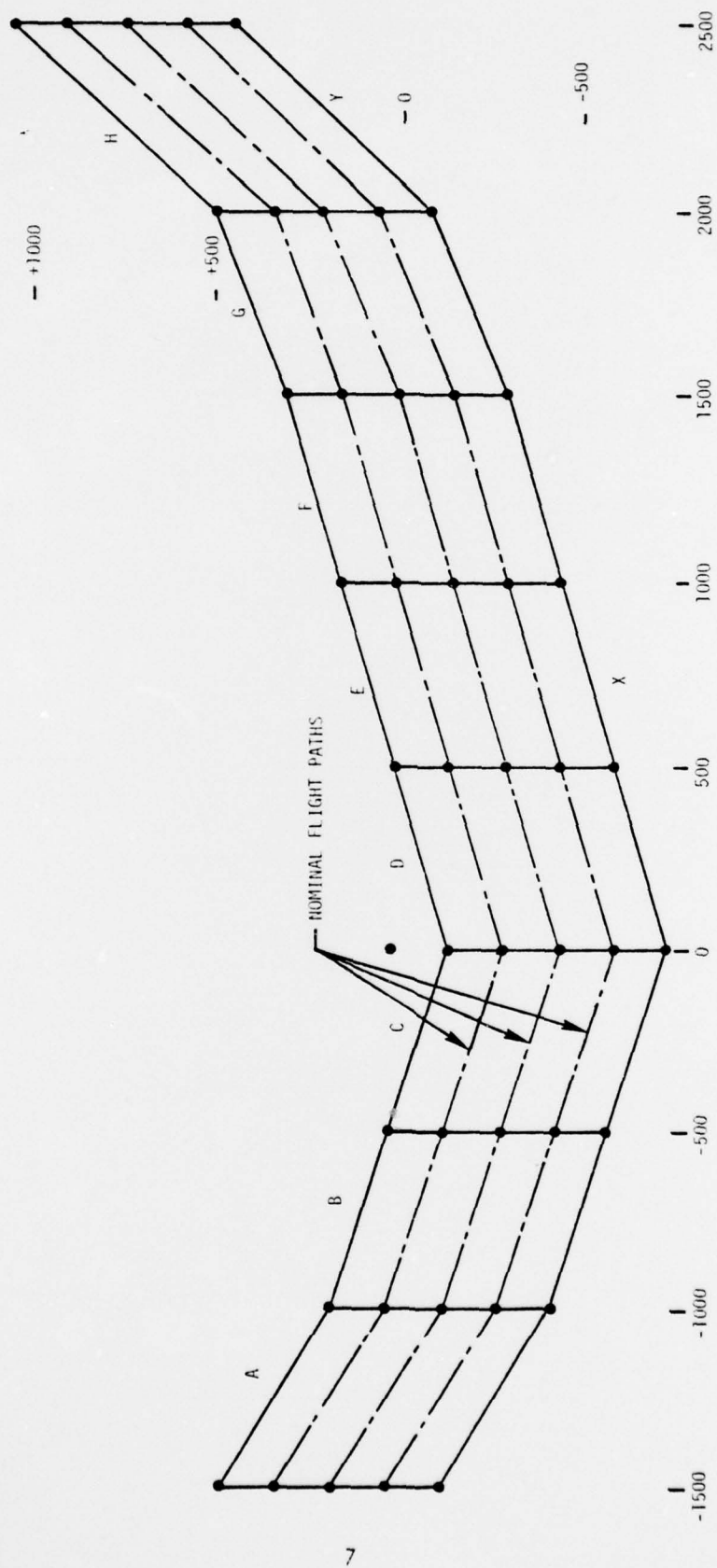
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Figure 3. Visual Data Base Area

Figure 4. Visual Data Base Sectors and Flight Paths

Table 2. Nonreal Time Positions

Target Positions	Viewpoints					
T1		X	Y	Z	Line of Sight	Range
Tank on Road	1A	-785	-505	80	081°	750
X=-40, Y=-385	1B	-525	-520	55	085°	500
Z=4.0625	1C	-240	-530	30	044°	250
T2		X	Y	Z	LOS	Range
Tank in Field	2A	-780	-65	50	096°	750
X=-110, Y=-395	2B	-540	-140	35	131°	500
Z=2.9	2C	-280	-215	20	137°	250
T3		X	Y	Z	LOS	Range
Tank by Building	3A	-725	-300	45	106°	750
X=15, Y=-435	3B	-475	-325	30	103°	500
Z=4	3C	-40	-180	40	177°	250
T4		X	Y	Z	LOS	Range
Tank by Tree line	4A	575	-30	85	237°	750
X=-150, Y=-450	4B	265	-170	55	227°	500
Z=0	4C	55	-305	25	247°	250
T5		X	Y	Z	LOS	Range
No Target	5A	715	-530	95	277°	750
X=-35, Y=-440	5B	460	-540	60	280°	500
Z=0.625	5C	195	-540	30	293°	250
T6		X	Y	Z	LOS	Range
X=0, Y=0	6	2500	450	220	--	2700
Z=0						

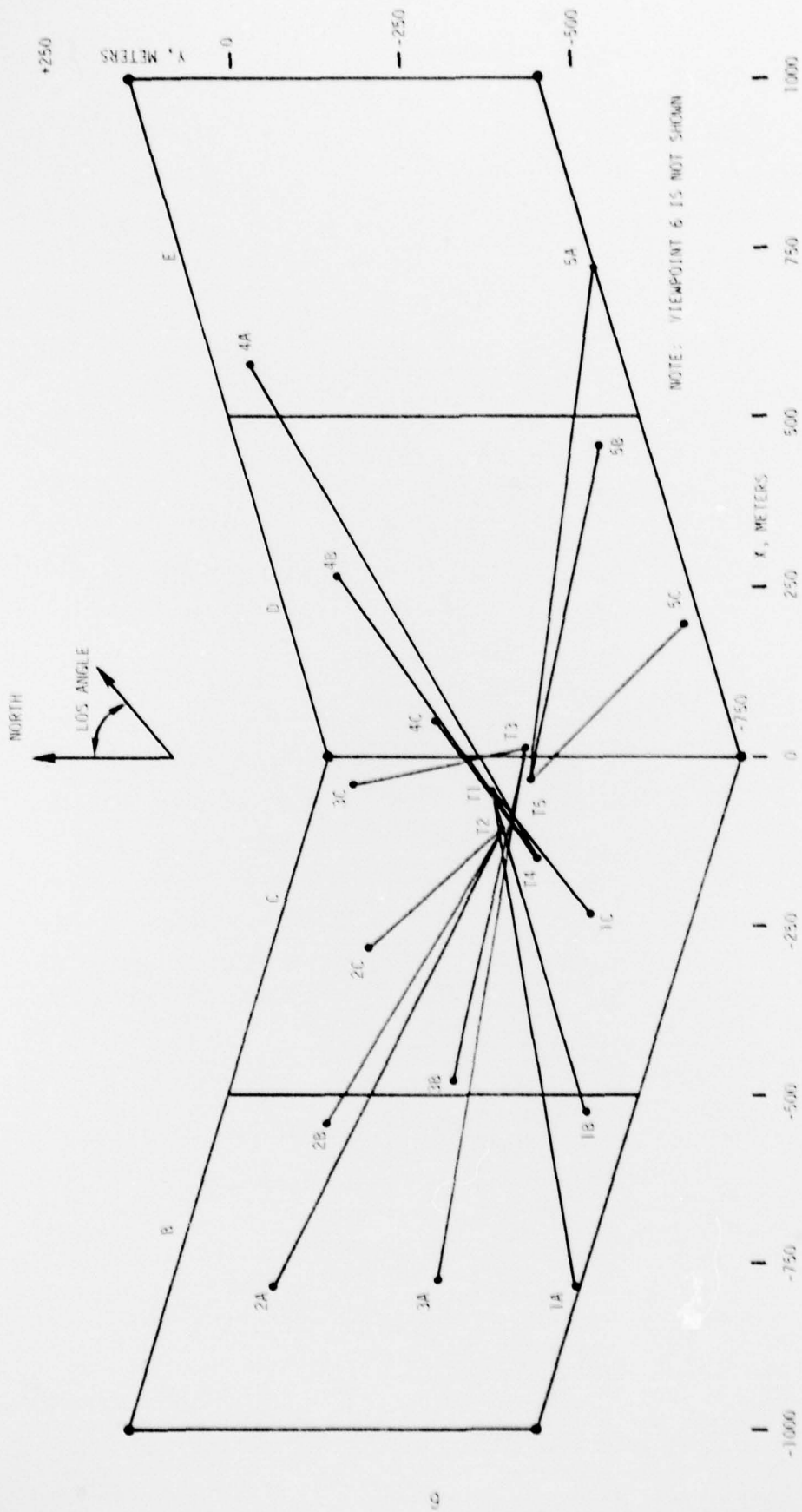The desired field of view was 86°H by 67°V.

Figure 5. Target and Viewpoint Locations Nonreal Time Scenes

In the present program, it was necessary to utilize a rolling terrain rather than a flat one. This necessitated modeling the terrain with three dimensional models. In addition, it was necessary to have many three dimensional models on the terrain simulating trees, groups of trees, and buildings.

The resulting visual data base exceeded the specified 10,000 edges. It contained rolling terrain made up of flat planar faces. For groups of trees, peaked irregular shaped blocks were used. Where not limited by the 16 faces per object rule, the exterior surfaces of the blocks were divided so that individual trees were apparent. Individual trees were also used where the system constraints on objects per model and separation planes permitted. Houses, sheds, barns, churches, lakes, creeks, roads, and fields were included in the visual data base where they were indicated on the map used. The tree groups and individual trees were also placed as indicated on the maps used. The system used did not have texturing, curved surface shading or sun shading. Hence, point features and faces were used for texturing. The face colors were selected to give the effect of sun shading.

The original map utilized was a U.S. Army map of the Petrey, Alabama area with a scale of 1:50,000. This meant that the entire visual data base area of 600 by 4000 meters was approximately 1/2 inch by 4 inches on the map. This proved unsatisfactory since the necessary cultural and/or terrain details essential to a usable data base could not be determined from the detail available at that scale factor. Necessary details include:

1. Terrain elevation (contour lines)

2. Water features as rivers, lakes, shoreline

3. Type of terrain with color texture (farms, forest, etc.)

4. Cultural features such as railroads, industrial plants, airports or airfields, isolated buildings or urban developments.

Later, a Geological Survey map of a scale of 1:24,000 was used. In addition to the maps, a 16mm film made by a helicopter flight in one pass over part of the area was available. It would have been desirable to have even greater map detail and to have low level aerial photographs of the entire area.

The nonreal time visual data bases were prepared using the real time visual data base to generate scenes of the aim points from the required viewpoint given in Table 2. These were photographed and used as the base scene for adding details to obtain the required 2000, 4000, and 8000 edge scenes. This additional detail or scene enhancement was accomplished using an Applicon graphic system as an aid for the visual data base modeler.

The tank used in the nonreal time scenes was a Russian T-62 tank which had been previously modeled for the real time system.

PROCEDURES

REAL TIME

The first step in preparing the required real time film strips was the preparation of the visual data base described in the last section. Once this visual data base had been satisfactorily prepared, i.e., it did not overload the equipment, the next step was the planning of the flight paths. It should be noted that to avoid overload, it was necessary to utilize a 40^0H by 30^0V field of view.

Three flight paths were needed, two in one direction and one in the other direction. One was to be longwise down the center of the modeled area. The others were at approximately the one-quarter and three quarter width points. The flight paths were digitally recorded in the computer by flying them at 45 knots and making sure that the resulting scenes were visually satisfactory. To do this, required some adjustments to the flight paths. In order to avoid overloading the CIG system, not all of the visual data base sectors could be entered at once. Thus, the first few sectors were entered and when the first of these had been flown over, another sector was entered into the equipment. While doing this, a pause was made in following the flight path. This process was continued until the entire data base was flown over.

In order to record the visual data, the scenes were generated and viewed by a high quality TV color camera (Figure 1) with its output recorded on a video tape recorder. The resulting video tape was converted to 16mm films by an outside contractor.

NONREAL TIME

The objective of this procedure was to make the required 48 scenes from 16 locations in three different amounts of scenic content. The Visual scenes were generated using the real time data bases and the aim points and viewpoints of Table 2 and a reduced field of view. This field of view reduction was made in order to avoid system overloading. The generated scenes from the selected viewing points were photographed by Polaroid monochrome film on the high resolution Dicomed recording unit.

Photographic enlargements of this scene were then made and used to determine the scenic enhancement required to reach the desired values of 2000, 4000, and 8000 edges.

Once the required enhancement for each of the forty eight scenes had been determined and added by means of the Applicon unit the resulting visual data base information was processed.

Originally this was done via the PDP 11/35 computer and later via the VAX 11/780 computer, and stored on a magnetic tape. The contents of this tape was then transferred to the refresh digital memory and viewed on the TV monitor. At this stage, the face colors were adjusted to the satisfaction of the viewer. Then the scene was photographed and copies for distribution made.

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SYSTEM SIZE AND BUDGETING COSTS

SYSTEM SIZE

In sizing a CGI system for use in training navigators and/or pilots, certain assumptions must be made. Will the overall simulator be a part task trainer or a full mission/crew training simulator? The answer regarding the intended use will determine the size of the image generator, display type and field of view, and the resultant cost.

With the foregoing in mind two systems will be described: 1. a basic single channel system for use in a part task trainer; 2. a basic 3-channel system as the least complex necessary for a mission simulator. Each of these basic systems would have the capability for expansion to include larger field of view, greater scene texturing detail and special effects such as circle feature generation. These capabilities could be incorporated as design evolutions and technology advancements mature.

SINGLE CHANNEL SYSTEM

Table 3 delineates the representative performance characteristics of a CGI system with one (1) video channel.

The image generator hardware would consist of 10 to 12 electronic enclosures (standard 27 inch) supplemented with a 32 bit general purpose computer and peripherals for control and interface with the vehicle simulator.

The display system would consist of a high resolution color CRT and electronics with appropriately designed mirror/beamsplitter optics to present the scene at an effective infinity focus. The display module is approximately 30 inches wide by 30 inches deep by 50 inches high.

THREE CHANNEL SYSTEM

Table 4 delineates the representative performance characteristics of a CGI system with three (3) video channels. It should be realized that additional video channels and a display system producing greater field of view (dome/projector systems or a mosaic of in line infinity optics windows) are currently being examined for state of the art configuration.

The image generator hardware would consist of approximately fourteen 27 inch electronic enclosures supplemented with a general purpose computer and peripherals.

The display system would consist of three single window modules juxtaposed in a wrap-around configuration to produce a continuous wide angle field of view. The width is approximately 8 feet, depth 4 feet, and height approximately 50 inches.

**Table 3. Representative Performance Characteristics
of Single Channel System**

```
IMAGE GENERATOR

      Maximum Potentially Visible Edges        2000-3000
      Edge Crossings/System Raster Line        256
      Variable Size Point Features             4000
      Scene Update Rate/Second                 30
      Raster Lines/Frame Total                 875
      Number of Video Channels                 1
      Number of Moving Models                  3
      Number of Viewpoints                     1
      Number of Colors                         256
      On Line Data Base Capacity               10,000

DISPLAY SYSTEM

      Single Window Display with Infinity Optics
      and High Resolution Color CRT

      Field of View                            30°-36°V by 40°-48°H

      Scan Lines/TV Frame                      875

      TV Frames/Second                         30

      Interlace Ratio                          2:1

      Elements Per Active Scan Line            1000
```

Table 4. Representative Performance Characteristics of Three Channel System

```
IMAGE GENERATOR

    Maximum Potentially Visible Edges              4000-8000
    Edge Crossing/System Raster Line               256
    Variable Size Point Features                   4000
    Scene Update Rate/Second                       30
    Raster Lines/Frame Total                       875
    Number of Video Channels                       3
    Number of Moving Models                        3
    Number of Viewpoints                           1
    Number of Colors                               256
    On Line Data Base Capacity                     20,000

DISPLAY SYSTEM

    Three Window Juxtaposed Display with Infinity
    Optics and High Resolution Color CRT

    Field of View                                  30°-60°V by 105°-120°H

    Scan Lines/TV Frame                            875

    TV Frames/Second                               30

    Interlace Ratio                                2:1

    Elements Per Active Scan Line                  1000
```

BUDGETING COSTS

The systems described would result in cost estimates for basic hardware in 1979 dollars as follows:

	Single Channel System	Three Channel System
Image Generator	$2,300,000-$2,600,000	$3,500,000-$4,000,000
Display	$ 100,000-$ 150,000	$ 350,000-$ 400,000

Cost ranges delineated are representative of current configurations being offered in the industry. Support and logistics requirements of particular procurements would, of course, reflect in additional total system costs.

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REFERENCES

1. U.S. Army map of the Petrey, Alabama area   Scale 1:50,000

2. U.S. Geological Survey, 7.5 minute series (topographic) map of the Petrey Quadrangle, Alabama

3. Map Interpretation and Terrain Analysis Course, Route 27

    --Self Instruction Manual
    --Map of area
    --16mm film from helicopter flying course

4. Letter from Dr. William R. Bickley of the Army Research Institute, Ft. Rucker, Alabama, dated 4 August, 1977.

5. GE, Space Division, Proposal No. 702008, "Proposal for the Laboratory Development of Computer Generated Image Displays for Evaluation in Terrain Flight Training, 20 October, 1976.

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